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A Comparison of Fiber Orientation on Fourdrinier and Verti-Forma Paper Machines Using the Instron Tensile Tester

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A COMPARISON OF FIBER ORIENTATION ON FOURDRINIER AND VERTI-FORMA PAPER MACHINES USING THE INSTRON TENSILE TESTER

by

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ABSTRACT

Many of the fundamental sheet properties are interrelated with the fiber orientation of the sheet. Until recently, this sheet was made on a Fourdrinier machine and the relationships were thoroughly studied. The advent of the Verti-Forma has opened up a new field of study. The objective of this thesis was to compare the fiber orientation in the two-wire Verti-Forma with the conventional Fourdrinier using the Instron tensile tester.

Test samples were acquired from the pilot Fourdrinier at Western Michigan University, a Fourdrinier at Allied Paper Company, and the Verti-Forma also at Allied. Full and split sheet halves were tested for elongation, TEA, and tensile at angles of 0°, 30°, 60°, and 90°.

The Verti-Forma reduced the two-sided effect of the conventional Fourdrinier. The average percentage differences of the test values of both the top and bottom sides of the Verti-Forma sheet for TEA, tensile, and elongation were lower than the percentage differences of both Fourdriniers. Full sheet tensiles showed that the overall fiber alignment wasn't changed by the Verti-Forma, the only change was in the alignment of the individual sides. The bottom side of the Verti-Forma was slightly stronger than the topside.

The differences in the Fourdriniers were mainly due

to machine speed. The Fourdrinier with the higher speed had more fiber alignment in both the full sheet and split-sheet halves. This gave a higher degree of two-sidedness.

The fiber counting procedure, the basic method for determining fiber orientation, proved to be unsuccessful for this study. The fiber axial direction could not be determined accurately.

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HISTORICAL BACKGROUND

A very important phenomenon in papermaking is the fact that fibers tend to align themselves in the machine direction in paper formed on the Fourdrinier paper machine. This is caused by the combing action of the wire. Throughout the years papermakers have been attempting to measure this degree of fiber alignment. In 1925 Jacobsen (1) developed the zero span tensile tester. He related the ratio of the tensiles in the machine direction and cross direction to the fiber orientation of the sheet. In 1938 Bryant and Lamar (2) did a photographic study of the motion of fibers in a water suspension. This study revealed a definite fiber alignment in the direction of flow. However, there appeared to be no possibility of measuring the orientation of successive layers of fibers through the paper, and therefore the simplified viewpoint was adopted of two sides to the paper, the wire side and the top side.

The distribution of fiber orientation on these two surfaces was measured by Danielson and Steenberg (3) in 1947. Their method consisted of dyeing a small amount (1%) of fibers and adding these to the stock on the paper machine. The dyed fibers were then counted as either being in the machine direction or cross machine direction of the sheet. This method was further improved by Glynn, Jones, and Gallay (4) in 1959. They dyed the fibers after they had been formed into a sheet on the paper machine. Fiber counts were taken at 7½ degree intervals from 0^{o} (machine direction) to 90^{o} (cross direction) to get an overall picture of fiber orientation on each side.

In 1958 Dearth, Lathrop, Van den Akker, and Voelker (5) did a study on fiber strength. In this study they revised the method of the zero span tensile test developed by Jacobsen (1). This method was accepted as a TAPPI standard (6) in 1960.

A study of fiber orientation was done by Friedlander (7) in 1958. He used x-ray diffraction patterns to determine the degree of arrangement of fibers. Although this was less time consuming than most tests, the average mill is not equipped to run it. Borrunso (8) developed another technique about this same time. He related the dimensional changes of paper in caustic soda to fiber orientation. In 1965, Friele (9) measured fiber distribution with the aid of dichroism.

The latest technique published involves the use of the Beloit sheet splitter developed by Mih and Parker (10) and the zero span tensile tester. In this study Kallmes (11) advances the work of Jacobsen (1) by applying the zero span tensile test to the different layers of a sheet. Therefore, he develops a good picture of the fiber orientation distribution throughout the thickness of a sheet.

The study of fiber orientation on the Fourdrinier is pretty thorough. But there is limited information published on the fiber orientation of paper made on other types of paper machines. In 1957 Pusyrev (12) did a study of the dry process in the Soviet Union where random orientation can be achieved. Kallmes (11) mentioned in the above paragraph, measured the fiber orientation distribution of Xerox copy paper which he believed came from a double wire machine. With the development of the Verti-Forma by Black Clawson, a whole new field was open for orientation study.

All of these studies on fiber orientation have become increasingly important, for fiber orientation has been found to be interdependent with other sheet properties. To date, numerous works have been published which relate this interdependence. For example, Prusas (13) has studied the dependence of the strength properties on fiber orientation. In addition, Gallay (14) has related curl to fiber alignment in the sheet. As a result of these many developments, there has been an added incentive to delve deeper into the area of fiber orientation.

PRESENTATION OF THE PROBLEM

In the preceding section, the historical background indicated numerous studies performed on paper from the Fourdrinier paper machine. Yet, more recently there has been the advent of the two-wire machine typified by the Black Clawson Verti-Forma. Since this area is relatively new, there has been very little published data on the Verti-Forma and its relation to fiber alignment.

The objective of this study was to determine what effect the Verti-Forma has on the fiber orientation of the sheet. This was to be determined by testing the full sheet and each side of the sheet against that of the Fourdrinier. In addition, the two-wire Verti-Forma was compared with the conventional single-wire Fourdrinier.

EXPERIMENTAL DESIGN

PREPARATION OF THE DYED FIBERS

The method of fiber counting as proposed by Danielson and Steenberg (3) was carried out in order to check the results obtained from the tensile tester. This method could be followed easily on the pilot machine by adding 1% dyed fibers to the machine chest and then counting the number of fibers lying in each direction in the paper. In the mill at Allied, even the advanced method of Glynn, Jones, and Gallay (4) might cause production upsets when used by an inexperienced hand. Therefore, the fiber counting method was run only on the pilot machine.

In the procedure followed, 1% of the fiber from the beater was removed after it had been broken up but before actual beating. The removed fiber was then dyed and washed to remove all traces of free dye. This dyed portion was then added to the machine chest and mixed thoroughly with the rest of the stock. Random samples were taken at the reel. An attempt was made to count the fibers lying at angles of 0°(CD), 30°, 60°, and 90°(MD), using a magnifying glass.

PREPARATION OF THE PAPER SAMPLES

Paper samples were taken at the reel on the pilot machine and after the rewinder at Allied. The basis weights were as follows: the pilot Fourdrinier - 36 lbs. per ream (25•38-500), the Allied Fourdrinier paper - 38 lbs. per ream and the Allied Verti-Forma paper - 30.5 lbs. per ream. The paper was conditioned according to TAPPI standard T402 m-49 before testing.

The sample-cutting procedure for each machine was identical. The test paper was cut into samples with respective angles of 0°(CD), 30°, 60°, and 90°(MD) according to TAPPI standard T481 sm-60. At each of the four angles twenty samples were cut one inch wide for immediate use on the tensile tester, and fifty samples were cut $2\frac{1}{2}$ inches wide by $5\frac{1}{2}$ inches long for use on the Beloit sheet splitter.

THE SHEET SPLITTING PROCESS

The samples from each machine were split using the Beloit sheet splitter (10). The samples were labeled and then soaked for one hour in a dilute caustic solution to break up the sizing. The sheet splitter dial settings vary with the amount of sizing in the sheet and with the basis weight. Personal experience is the best guide for determining the proper settings.

An attempt was made to split the samples into four equivalent layers, but this was unsuccessful. Therefore, the samples were split into approximate halves. About ten of the samples from each group of fifty had to be discarded because of poor splitting.

After splitting, the samples were dried 10 minutes on a microscope-slide hot plate under weights to minimize wrinkling and shrinkage. Then the samples were conditioned according to TAPPI standard T402 m-49. Each sample half was cut into a one-inch wide strip for use on the Instron tensile tester.

THE INSTRON TENSILE TESTER

The Instron tensile tester (15) was used to test the samples. Full-sheet and split-sheet halves were tested with respect to tensile, elongation, and tensile absorption energy. Each test sample was one inch wide, and a ten centimeter jaw separation was maintained during testing. The averages of each test were calculated and recorded in Table I - III. Each reading listed is the average of forty samples.

The zero-span tensile tester was not used, because the inaccuracies of the instrument become magnified at calipers less than .002 inches.

FIBER LENGTH DETERMINATION

In order to help analyze the tensile results, fiber classification tests were run on both sides of the sheet for each machine. The used tensile samples were combined from a given side of paper to form a composite five-gram sample. These samples were slurried using a blender. The tests were run using an M-46 Clark Pulp Classifier with screen sizes of 14, 30, 50, and 100 mesh. The percent held by each screen was calculated as was the fraction of fines that passed through the 100 mesh screen.

DISCUSSION OF EXPERIMENTAL RESULTS

TENSILE STRENGTH

Full sheet tensiles for all three machines are recorded in Table I. In each case, the tensile is greatest in the machine direction (90°) and constantly decreases to the lowest value in the cross direction. The tensile values of one machine should not be compared with another because of the differences in basis weights. Only the trends should be compared. In Fig. 1, tensile values are plotted using polar graph paper. The curves are reflected across the y-axis to represent the full 180° sheet. The basic shapes of the three curves show that the papers are very similar to each other. This indicates that the Verti-Forma does not reduce fiber alignment in the machine as depicted by the higher machine direction tensiles.

Split sheet tensiles are listed in Table I for all machines. A trend of decreasing tensile values from machine direction to cross direction is followed by all samples similar to the full sheet tensiles. The bottom side of the sheet is stronger at all angles for two of the machines, the pilot and the Verti-Forma. The Allied Fourdrinier, on the other hand, is stronger on the top side for the first two angles and then the bottom side becomes stronger.

In Fig. 2 the split sheet tensiles are plotted using polar graph paper. The curves of the Verti-Forma and the pilot Fourdrinier indicate that the two sides of each are fairly uniform with respect to tensile. The Allied Fourdrinier, however, has very dissimilar top and bottom sides. The higher machine speed between the Allied Fourdrinier and the pilot Fourdrinier seems to increase the fiber alignment in the machine direction. The Verti-Forma counteracts this speed effect with the two-wire system and reduces the machine direction alignment back to that of a low-speed Fourdrinier like the pilot machine. The effect is a one-sided sheet of paper.

FIBER LENGTH DISTRIBUTION

Results of the fiber classification tests are recorded in Table IV. In all three cases the concentration of fines was greater on the side of the sheet that contacted the vacuum boxes during formation. Suction seems to aid the migration of the fines in the sheet. On both of the machines from Allied, the stronger sheet side had the least fines, while the stronger sheet side from the pilot machine had higher fines. It appears as though the higher fines concentration can hurt tensile strength on high speed machines. This is a much debated point with many published articles, both pro and con.

The fiber length distributions are plotted in Figs. 3-5. In all three cases, both sides of the sheet are nearly matched in fiber distribution.

TENSILE ABSORPTION ENERGY (TEA)

Full and split sheet tensile absorption energies for all three machines are recorded in Table II and plotted in Fig. 6. The values for full sheet TEA increase from machine direction to cross direction for all samples. On the other hand, the split sheet TEA values in most cases tend to increase with increasing angle the exact opposite response of the full sheet. The Verti-Forma curves are more closely spaced giving another indication of a reduction of the two-sided sheet to a one-sided sheet. The low-speed pilot Fourdrinier has a less two-sided effect than the Allied Fourdrinier.

ELONGATION

Elongations for the full and split sheets from each machine are recorded in Table III. The values are quite scattered as shown in Fig. 7. The reason for the non-uniform behavior is probably due to the drying method employed after the sheet splitting process. The curves of the Verti-Forma and the pilot machine indicate that the two sides of each are more uniform than the two sides of the Allied Fourdrinier.

FIBER COUNTING METHOD

The fiber counting method attempted on the pilot machine was unsuccessful. The fibers could be counted but their axial direction could not be accurately determined because of fiber curl. This curling was largely due to the greater length of the fibers used for the dyed sample. To try to guess the axial directions would be defeating the purpose of checking the tensile method.

TABLE I. FULL SHEET AND SPLIT SHEET TENSILES*

PILOT FOURDRINIER

Angle of Measurement	Full Sheet	Felt Side	Wire Side
90°(MD)	6.93	1.50	1.61
60°	5.54	1.18	1.34
30°	3.91	0.86	0.92
0°(CD)	3.48	0.70	0.89

ALLIED FOURDRINIER

Angle of Measurement	Full Sheet	Felt Side	Wire Side
90°(MD)	8.76	2.78	1.26
60°	6.25	1.63	1.25
30°	4.79	1.07	1.17
0°(CD)	4.28	0.94	1.05

ALLIED VERTI-FORMA

Angle of Measurement	Full Sheet	Top Wire	Bottom Wire
90°(MD)	6.04	1.50	1.70
60°	4.00	0.93	1.10
30°	2.62	0.68	0.75
0°(CD)	2.29	0.62	0.67

* Tensile Units in Kilograms

TABLE II. FULL SHEET AND SPLIT SHEET TENSILE ABSORPTION ENERGIES (TEA)*

PILOT FOURDRINIER

Angle of Measurement	Full Sheet	Felt Sheet	Wire Side
90°(MD)	2.72	0.62	0.73
60°	2.81	0.61	0.82
30°	3.16	0.51	0.67
0°(CD)	3.80	0.38	0.58

ALLIED FOURDRINIER

Angle of Measurement	Full Sheet	Felt Side	Wire Side
90°(MD)	3.81	0.89	0.37
60°	4.04	0.68	0.46
30°	5.36	0.50	0.48
0°(CD)	6.22	0.42	0.53

ALLIED VERTI-FORMA

Angle of Measurement	Full Sheet	Top Wire	Bottom Wire
90°(MD)	2.88	0.58	0.64
60°	3.60	0.44	0.48
30°	3.63	0.30	0.37
0°	3.42	0.29	0.33

* TEA Units in Kilograms/Centimeter

TABLE III. FULL SHEET AND SPLIT SHEET ELONGATIONS*

PILOT FOURDRINIER

Angle of Measurement	Full Sheet	Felt Side	Wire Side
90°(MD)	1.66	1.42	1.46
60°	1.98	1.72	1.96
30°	2.92	1.78	1.96
0°	3.40	1.64	1.88

ALLIED FOURDRINIER

Angle of Measurement	Full Sheet	Felt Side	Wire Side
90°(MD)	1.56	1.40	1.42
60°	2.02	1.88	1.64
30°	2.76	1.76	1.86
0°	4.12	1.76	2.26

ALLIED VERTI-FORMA

Angle of Measurement	Full Sheet	Top Wire	Bottom Wire
90°(MD)	1.48	1.96	1.74
60°	2.52	2.18	1.90
30°	3.72	2.00	1.90
0°	3.90	2.08	2.02

* Elongation Unit in Percent

TABLE IV. PERCENT FIBER LENGTH DISTRIBUTION IN EACH SPLIT SHEET

PILOT FOURDRINIER

Screen Size	Felt Side	Wire Side
14 mesh	5.11	4.06
30 mesh	23.46	22.84
50 mesh	25.75	25.72
100 mesh	20.81	19.46
Fines*	24.87	27.92

ALLIED FOURDRINIER

Screen Size	Felt Side	Wire Side
14 mesh	1.15	1.37
30 mesh	12.81	11.48
50 mesh	27.92	27.60
100 mesh	22.56	22.68
Fines*	35.56	36.88

ALLIED VERTI-FORMA

Screen Size	Wire Top	Wire Bottom
14 mesh	0.72	0.38
30 mesh	9.11	11.58
50 mesh	29.98	30.31
100 mesh	25.42	24.13
Fines*	34.77	33.59

* Fiber Passing Through 100 Mesh Screen

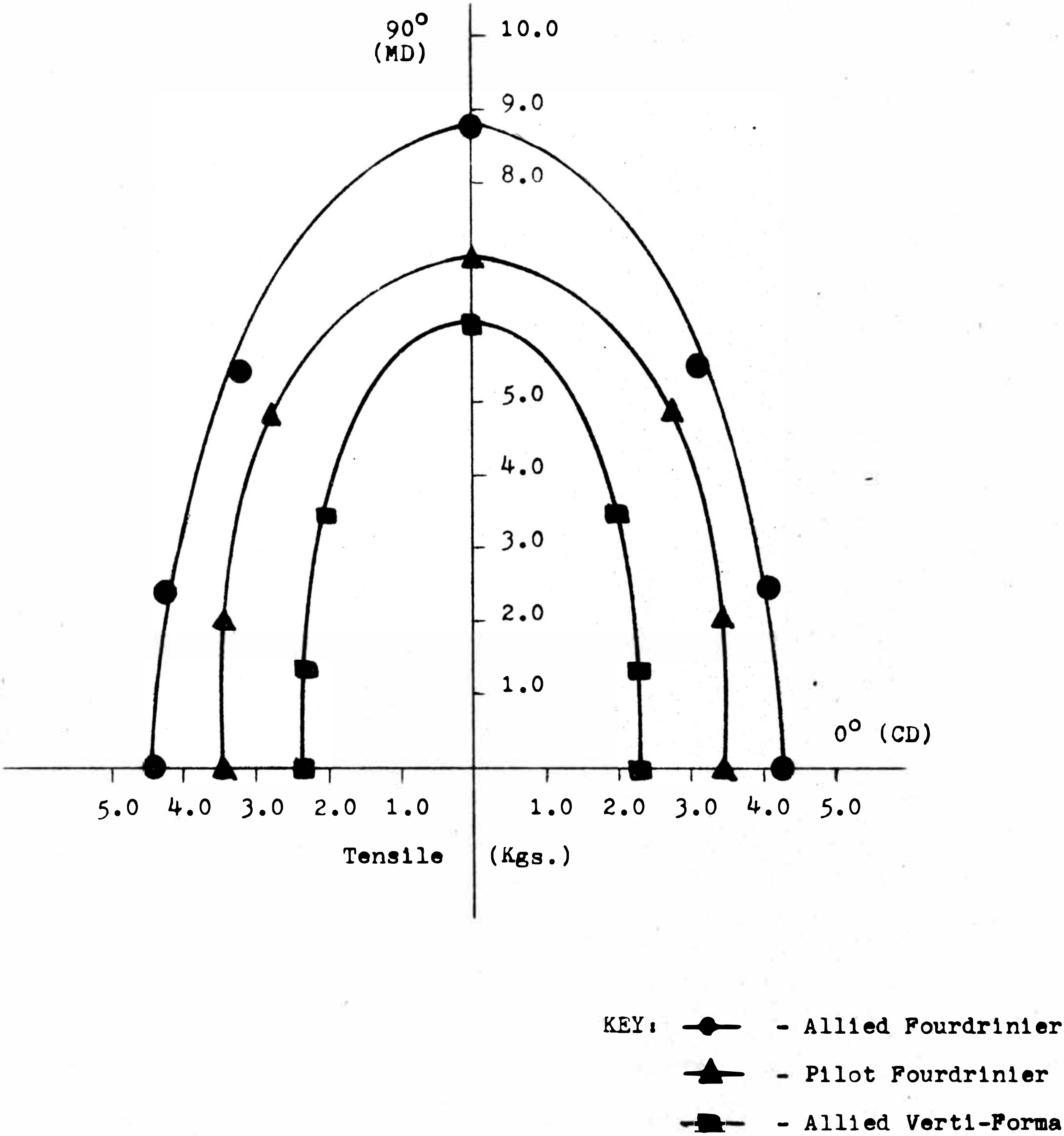

FIG. 1. POLAR GRAPH OF FULL SHEET TENSILE VS. ANGLE OF MEASUREMENT

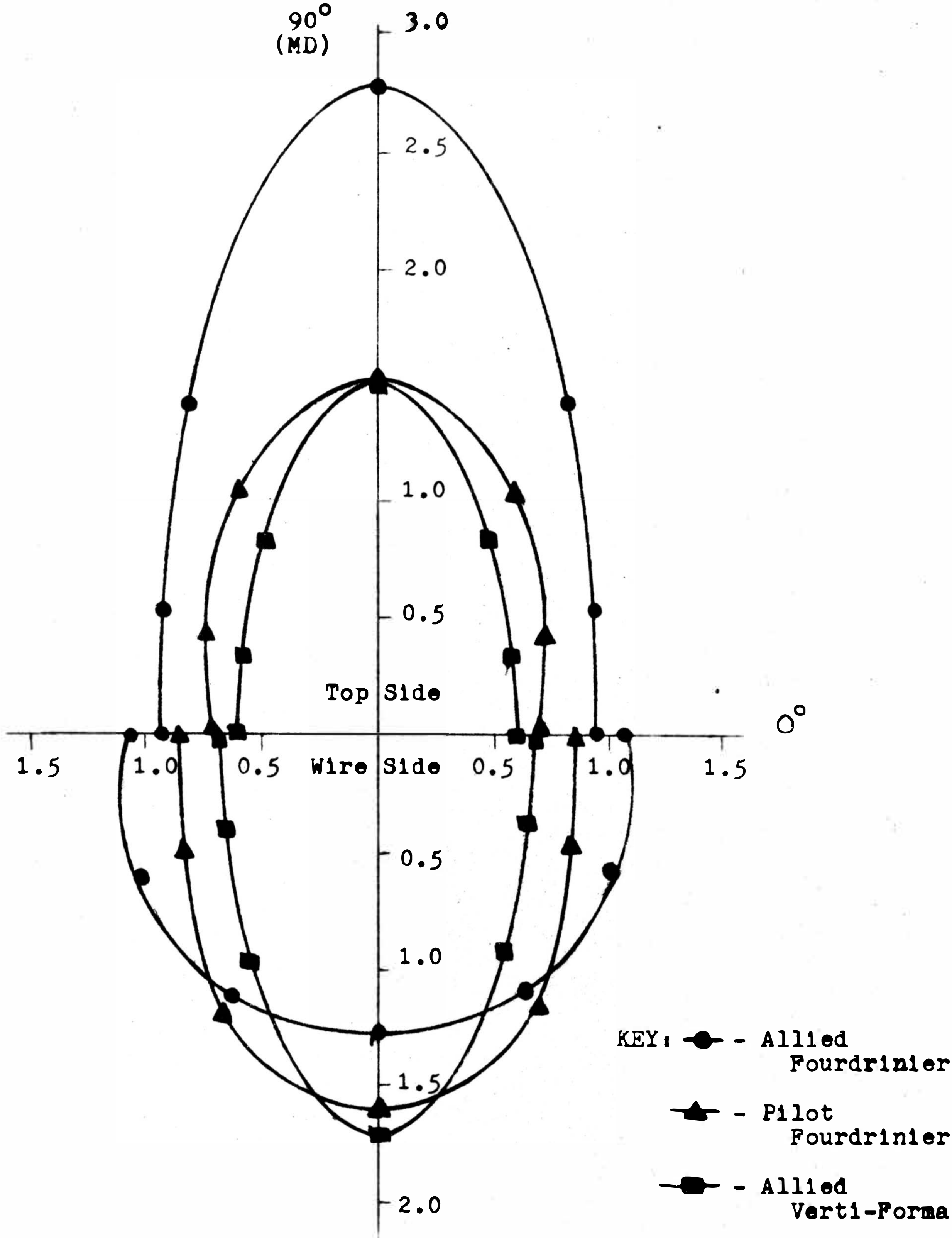

FIG. 2. POLAR GRAPH OF SPLIT SHEET TENSILES VS. ANGLE OF MEASUREMENT

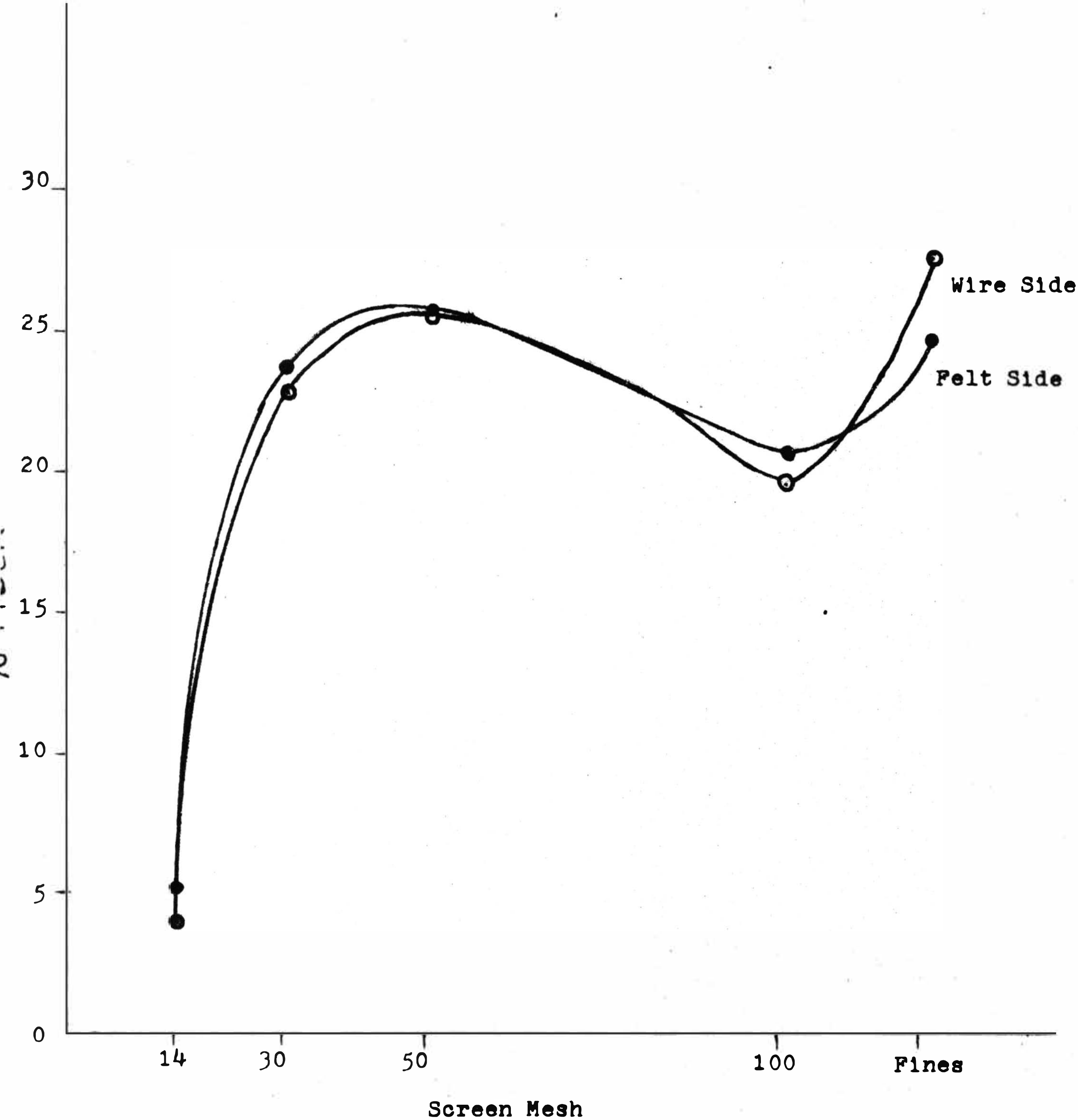

FIG. 3. GRAPH OF FIBER LENGTH DISTRIBUTION FOR EACH SIDE OF THE PILOT FOURDRINIER PAPER.

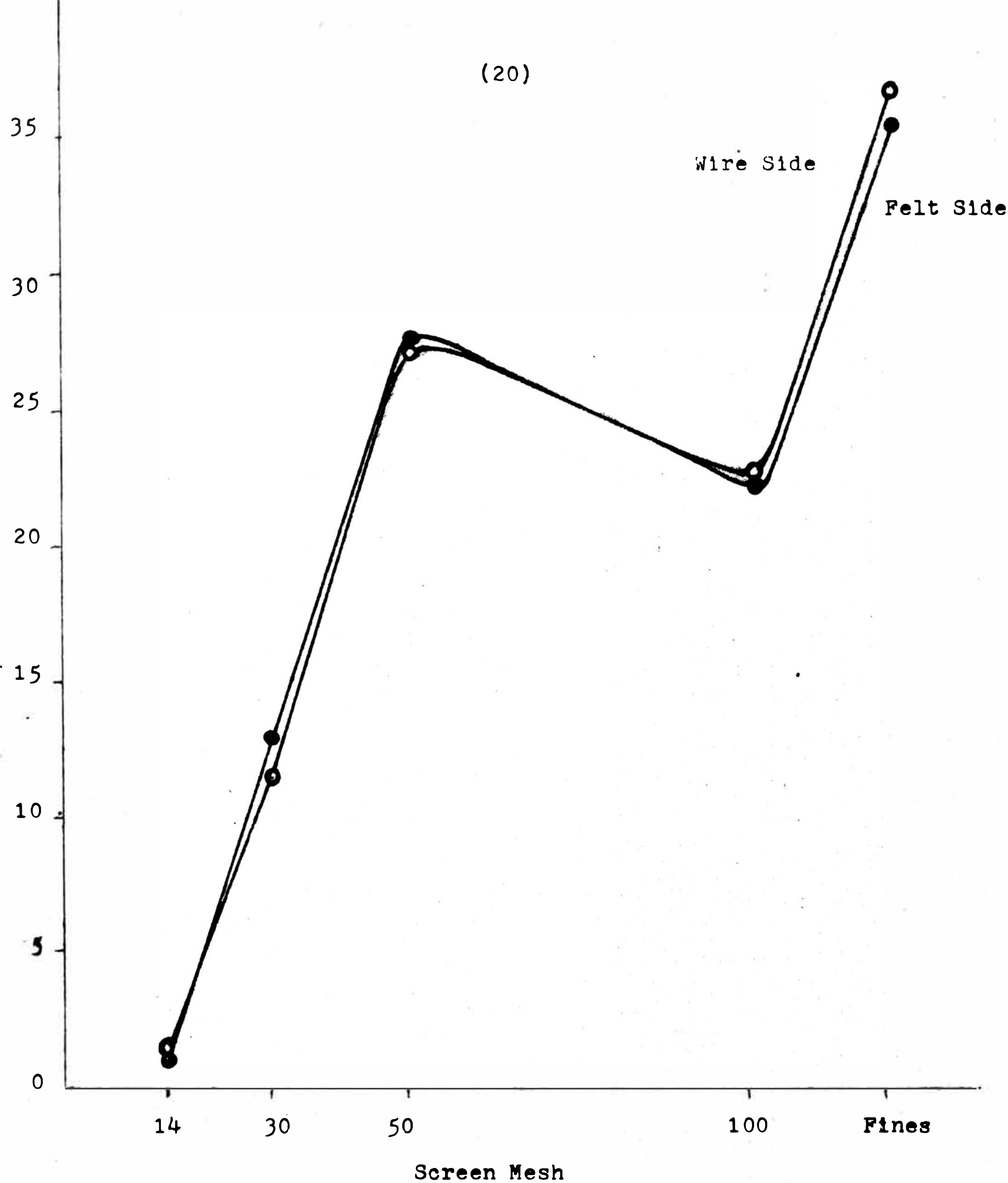

FIG. 4. GRAPH OF FIBER LENGTH DISTRIBUTION FOR EACH SIDE OF THE ALLIED FOURDRINIER PAPER

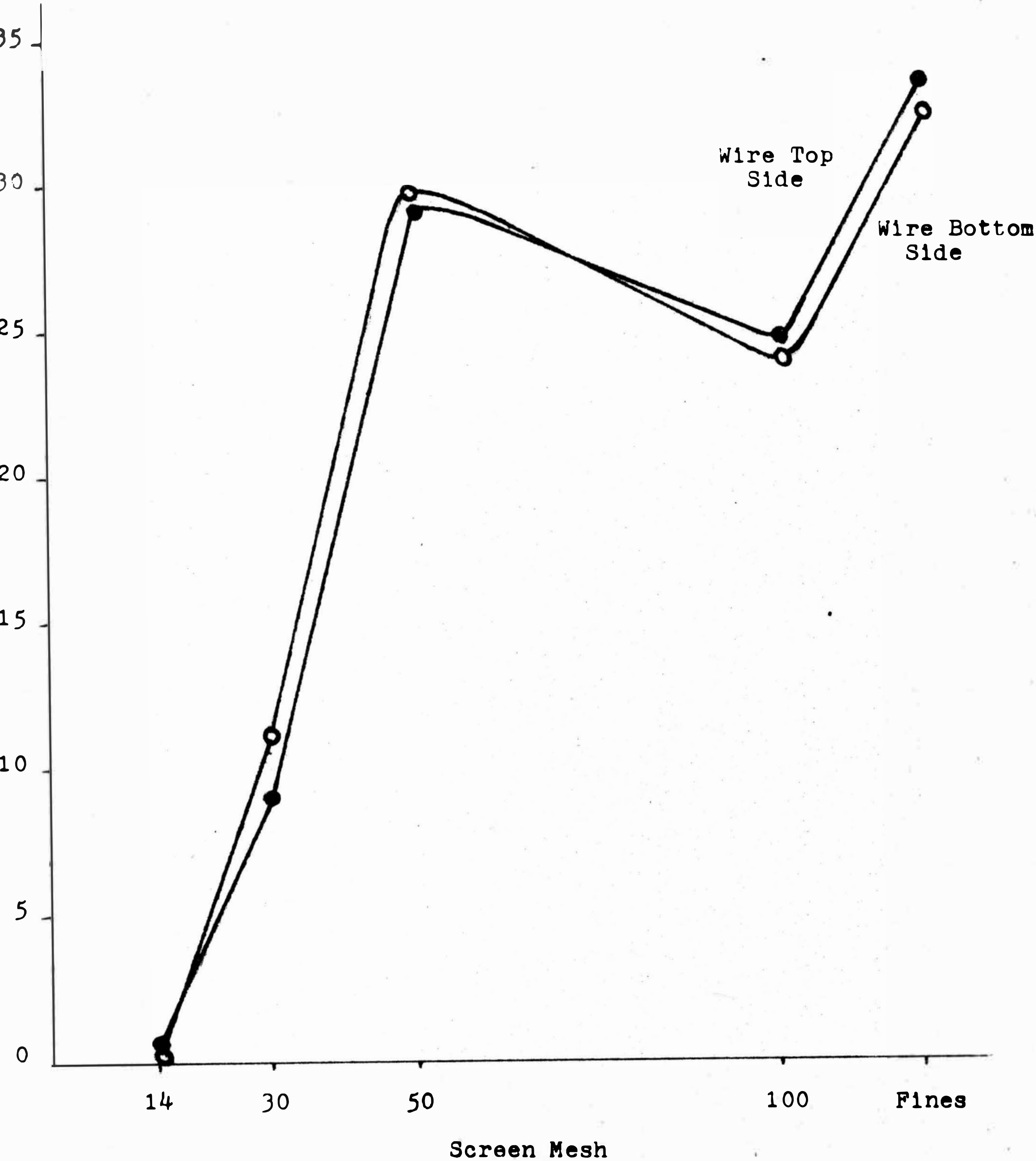

FIG. 5. GRAPH OF FIBER LENGTH DISTRIBUTION FOR EACH SIDE OF THE ALLIED VERTI-FORMA PAPER

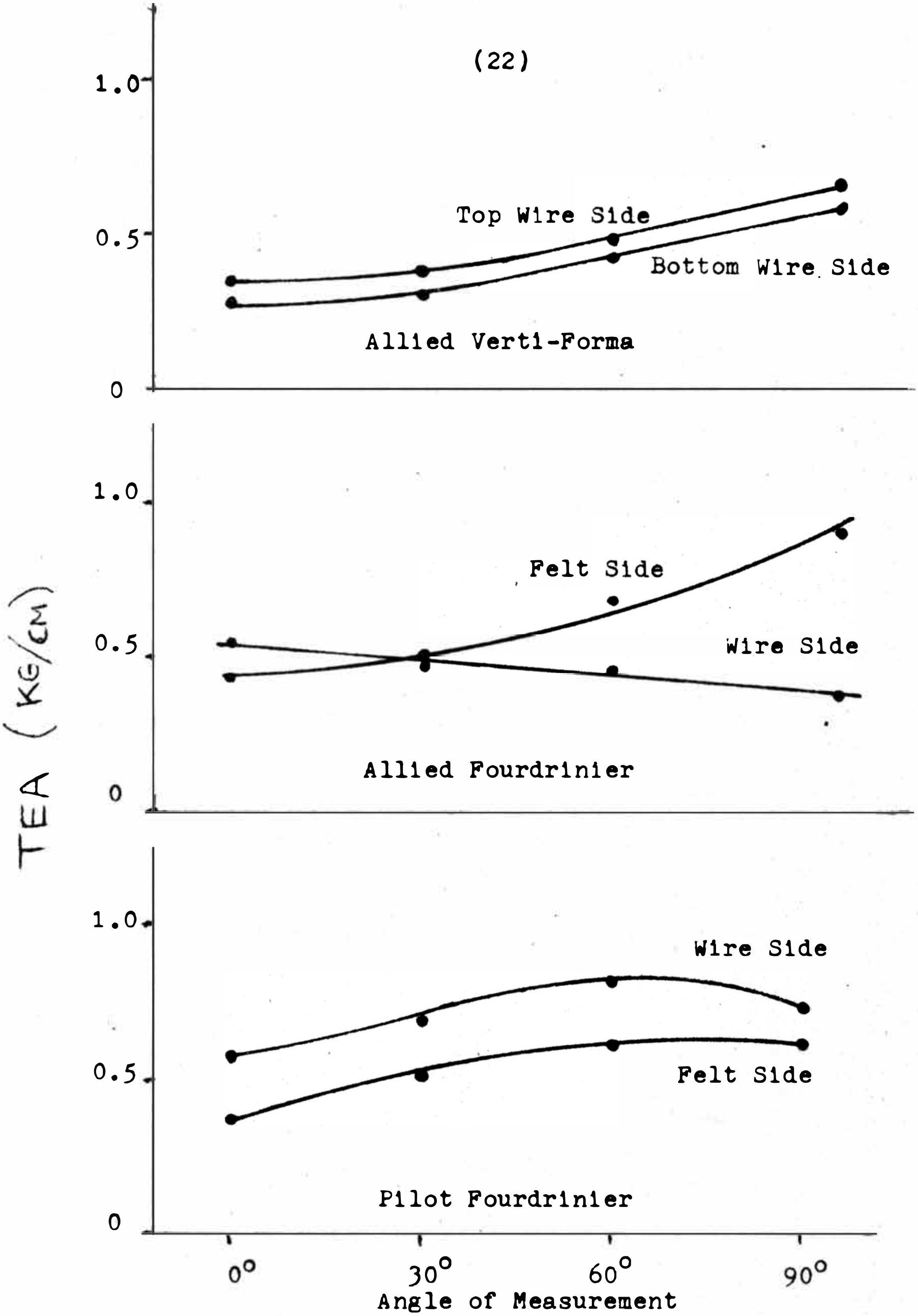

FIG. 6. GRAPH OF SPLIT SHEET TENSILE ABSORPTION ENERGIES VS. ANGLE OF MEASUREMENT

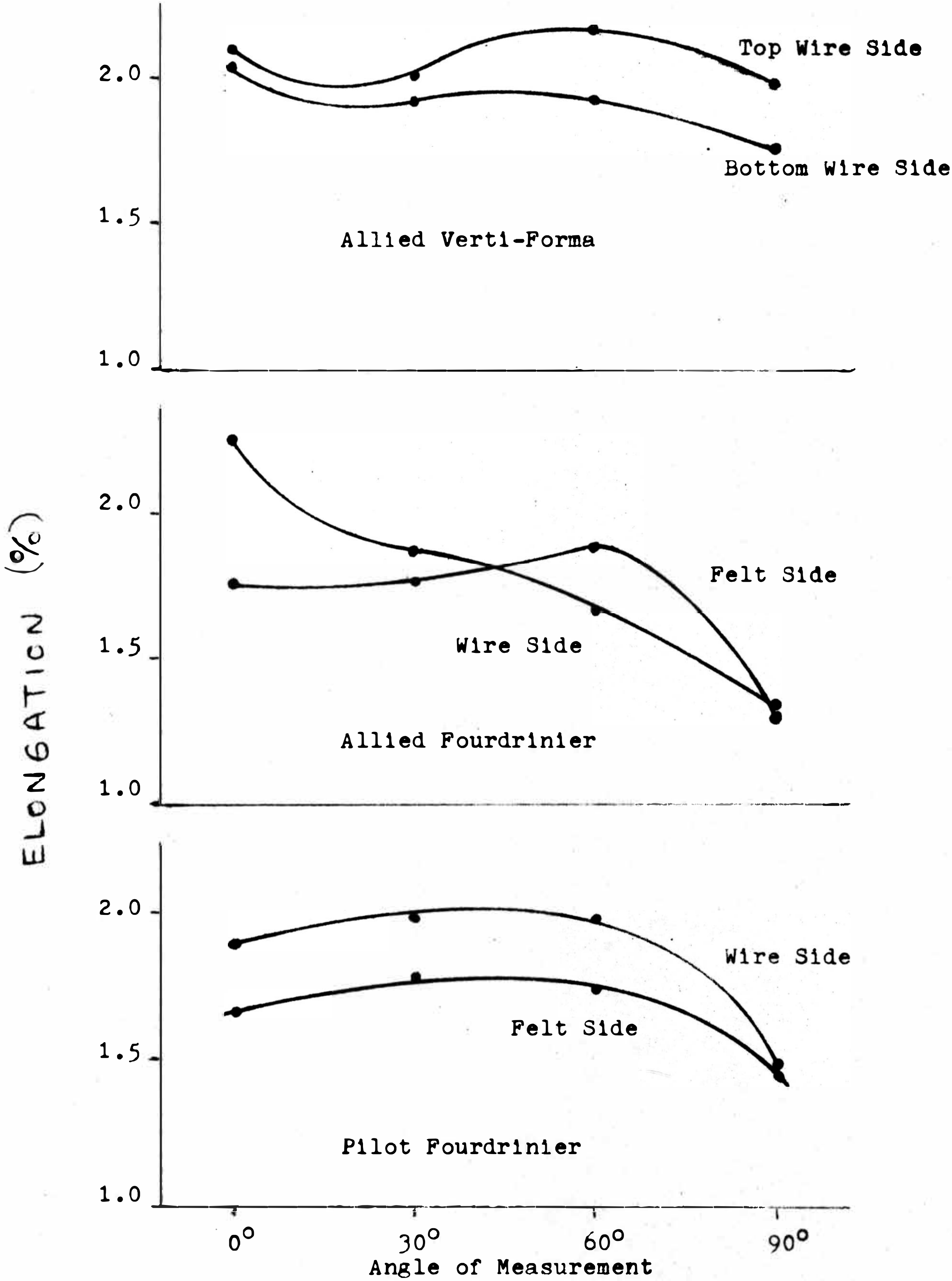

FIG. 7. GRAPH OF SPLIT SHEET ELONGATIONS VS. ANGLE OF MEASUREMENT

CONCLUSIONS

The results of this study have shown that the Verti-Forma greatly decreased the two-sided property of a sheet of paper. This was accomplished by the reduction of the machine direction fiber alignment in each split sheet half. The reduced machine direction fiber alignment lowered the average percentage differences in the top and bottom side test values. The average percentage difference in tensile was 12.2% for the Verti-Forma, 13.7% for the pilot Fourdrinier, and 42.5% for the Allied Fourdrinier. The average difference in elongation was 8.9% for the Verti-Forma, 10.3% for the pilot Fourdrinier, and 12.5% for the Allied Fourdrinier. For TEA the values were 14.2%, 30.7%, and 54.8%, respectively. In all three cases the Verti-Forma had the lowest percentage differences.

Although the two-sidedness was reduced in the Verti-Forma paper, it still was evident. The bottom side of the sheet was definitely stronger at all angles with respect to tensile and TEA.

The machine direction fiber orientation of the full Verti-Forma sheet was similar to that of the Fourdriniers. The shapes of the curves in Fig. I are identical for all practical purposes.

The Allied Fourdrinier which was run at higher speeds had the greatest two-sided effect. The pilot machine fell in between the Verti-Forma and the Allied Fourdrinier because of its slow speed. The higher machine speed magnified the fiber alignment in the Fourdrinier.

The fiber counting method for determining fiber orientation proved unsuccessful. The axial direction of the fiber could not be determined because of fiber curl.

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